

## PROLONGED ASSISTED CIRCULATION DURING AND AFTER HEART OR AORTIC SURGERY

- I. Prolonged partial left ventricular bypass by means of an intrathoracic circulatory pump.
- II. Diastolic pulsation of the descending thoracic aorta.

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At the last meeting of this SOCIETY we presented a technic for partial bypass of the left ventricle from the left atrium to the ascending aorta, utilizing an intrathoracic circulatory pump<sup>(1)</sup>. Subsequently, we developed a left ventricular bypass from the left atrium to the descending aorta<sup>(2,3)</sup>. The later procedure is safer, easier to perform and permits the use of an ideal tube-type pump. The bypass is accomplished by an intrathoracic circulatory pump operated by an external air source which could provide left ventricular support for several days or weeks. The clinical indication of this bypass should be in the treatment of left ventricular failure during or after heart surgery. At the present time the unit that we show in this report is ready for clinical use.

Two fundamental points were taken into consideration in developing this left ventricular bypass: the feasibility of long term support of the left ventricle and avoidance of heparin while functioning.

In the pioneer work of Kusserow on left ventricular bypass, abdominal or extra-thoracic pumps were utilized but heparin was required<sup>(4-6)</sup>.

The Intrathoracic Pump\* (Figure 1,2). In designing the tube-type #2 employed in this work, ideal hemodynamics were taken into consideration.

1. Blood progresses in one direction only.
2. Blood is expelled by a squeezing motion rather than a compression chamber.
3. Systolic residue remains in the central lumen.
4. Circulatory stasis is avoided.
5. There is minimal contact of blood with foreign materials.
6. Heparin is not required while functioning.

The pump consists of a .030" thickness radiopaque Silastic tube reinforced with Dacron 116<sup>+</sup>.

Another .045" thickness Silastic tube reinforced with Dacron 116 encases the internal Silastic tube and acts as a housing with only one inlet. This inlet is connected to an external air source. Pressured air entering the housing collapses the Silastic tube, thus emptying it of its contents. The valves (ball type) at either end cause the flow to be unidirectional. This system can be used without danger of atrial collapse in a partial bypass.

The inlet tube plays an important role in the pump's functioning. It is made of Silastic to facilitate the maneuver of insertion and has a funnel shape in order to keep the left atrium in adequate position and encourage the blood inflow to the pump.

The Extrathoracic Air System (Figure 3). The extrathoracic air system, in which the power is derived from a compressed air line or an oxygen tank, consists of a solenoid valve coupled to an expanded Teflon bellows. The air volume output can be varied from zero to 60 ml. per stroke. The control circuit can be triggered by a variable frequency oscillator or can be triggered by the R wave of the patient's electrocardiogram, thus allowing the intrathoracic pump to operate at any preselected time of the patient's cardiac cycle. In the absence of the patient's R wave, due to fibrillation, or if the cardiac rate falls below a preselected level, the system automatically reverts from R wave triggering to the variable frequency trigger. The apparatus is also provided with a safety mechanism

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\* Available for experimental purposes, by non-profit institutions under special order from Baylor University College of Medicine.

+ Silastic, siliconade rubber from Dow Corning, Midland, Michigan.

which consists of a rolling diaphragm pump\* operated by an electrical motor. The latter system cannot be triggered with the patient's electrocardiogram.

## RESULTS

During pumping the left ventricle decreases in volume and the heart rate frequently is diminished.

The reduction of the left ventricular work in Kg. -M. (computed by the formula: the product of left ventricular output (aortic flow) in L. /min. divided by 100 and the plane-metrically-integrated mean systolic pressure in ml. of water) was proportional to the reduction of the left ventricular output.

Left intraventricular pressure. During pumping some components of the left intraventricular pressure pulse appeared reduced (Figure 4).

A reduction of the peak of systolic ventricular pressure occurred (an index to assess the maximal tension developed by the left ventricle)<sup>(7)</sup>. There was a reduction of the systolic duration (an index of the duration of the tension state determined by measuring the time interval between the onset of the isometric contraction and the closure of the aortic valve). Therefore, there was a reduction of the area beneath the systolic component of the left ventricular pressure pulse. This area is related to the tension-time index measurement for each contraction which is an index of the total tension developed by the left ventricle and related as the hemodynamic determinant of the myocardial oxygen consumption<sup>(8)</sup>. The slope of the ventricular pressure rise was decreased. (An index that reflects a decreasing in the myocardial contractility)<sup>(9-11)</sup>. Therefore, a reduction in the external stroke work, in the external stroke power (stroke work per systolic second) and in the rate of development of tension has taken place<sup>(12)</sup>.

The left intraventricular end-diastolic pressure remained unrelated to these changes. However, this work was performed in normal hearts. Pumping during diastole, an important peak of pressure (measured in 40-60 mm. Hg) was observed (Figure 5). When the coronary flow was measured a significant increase was seen<sup>(2,3)</sup>. Pumping during diastole provided maximal coronary flow.

Diastolic Compression of Descending Thoracic Aorta. A pneumatic sleeve wrapped around 5-8 cm. of the aorta and connected to an external air source triggered by the R wave of the electrocardiogram provided diastolic aortic pulsation (Figure 6). The extrathoracic pump employed for the left ventricular bypass (Figure 3) was utilized. In the work of Kantrowitz<sup>(13)</sup> a mobilized left hemidiaphragm was wrapped around the descending thoracic aorta and the left phrenic nerve stimulated during diastole. During the diastolic aortic compression a peak of pressure during early diastole and a reduction in the end-diastolic pressure was obtained (Figure 7). In this regard, the results are comparable with the intra-aortic pumping balloon technic reported by Kolff<sup>(14)</sup>. During diastolic pumping a volume of blood is mobilized preferentially in the cephalad direction. The magnitude of this response depends on the aortic diameter. The descending thoracic aorta of the dog is almost inadequate due to its small diameter. Therefore, the coronary inflow was not significantly increased (Figure 8), and the left intraventricular pressure did not change.

Another feature of this procedure should be the possibility of prolonged partial or total aortic compression allowing a proximal increase of the arterial pressure. It should increase coronary and cerebral circulation and should be indicated if pronounced hypotension is present. The implantation of the sleeve is a very simple technical problem. It only requires sacrifice of 2-3 pairs of intercostal arteries. The special closure system of the sleeve can be opened easily from outside the chest and thus, the sleeve can be removed without reopening the chest. It can operate continuously or intermittently without time limitation. The pneumatic sleeve consists of .030" thickness radiopaque Silastic reinforced with a Dacron 116 internal sheet. Another .045" thickness Silastic reinforced with Dacron 116 encases the internal sheet and acts as a housing with only one inlet. Pressured air entering the housing collapses the internal sheet and squeezes the aorta during diastole. Appropriate thickness distribution on the internal sheet provides maximal displacement of

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\* Rolling diaphragm. Bellofram Corporation, Burlington, Massachusetts.

blood in the cephalad direction and the aorta is compressed in anteroposterior direction (Figure 6).

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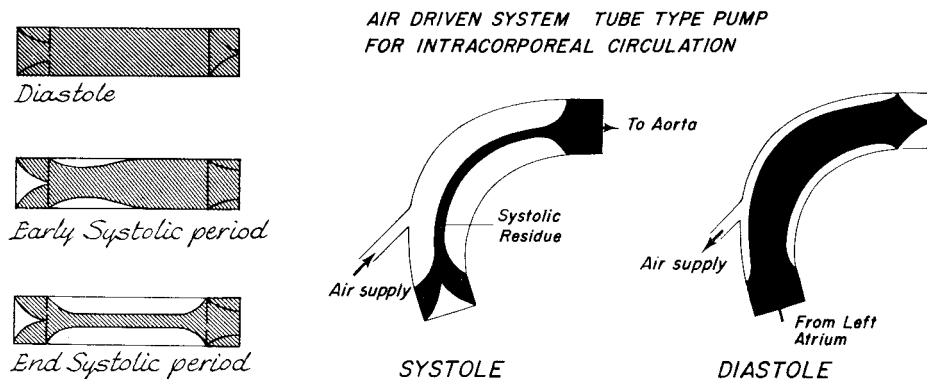


Figure 1. The ideal pump for intracorporeal circulation should be a simple contractile tube with a valve at either end. See explanation in text.

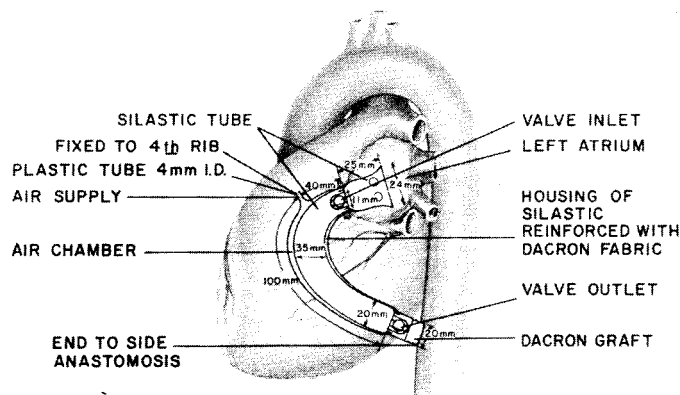


Figure 2. Left ventricular bypass with tube-type pump #2. The specifications in the drawing refer to a pump designed for clinical use.

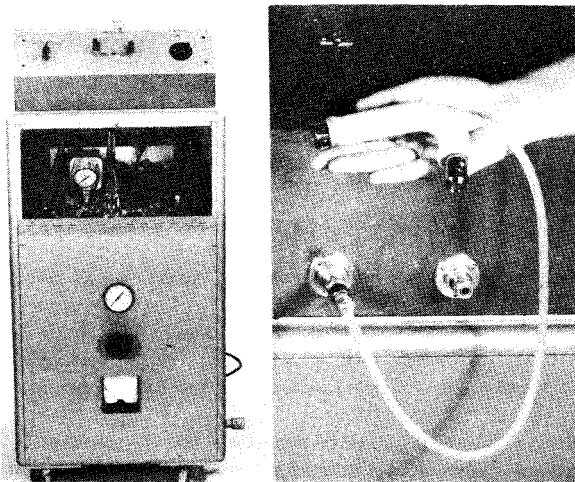


Figure 3. Extrathoracic air unit for clinical use. On the left an anterior view of the system is shown. On the right a partial posterior view showing the intrathoracic pump connected to the external unit can be seen.

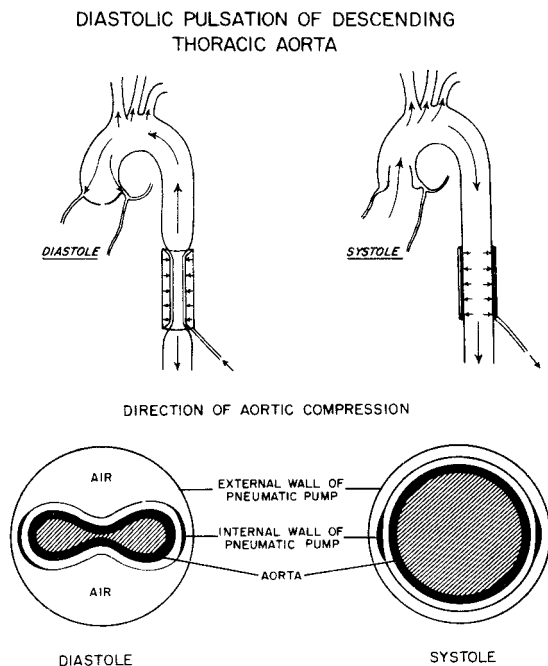


Figure 6. Diastolic compression of descending thoracic aorta. See explanation in the text.

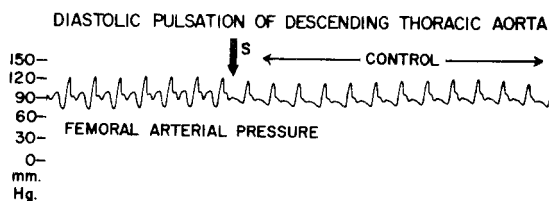


Figure 7. Femoral arterial pressure during diastolic compression of descending thoracic aorta. Before S: It is possible to see the diastolic wave originating from the pump and the end-diastolic pressure decreased.

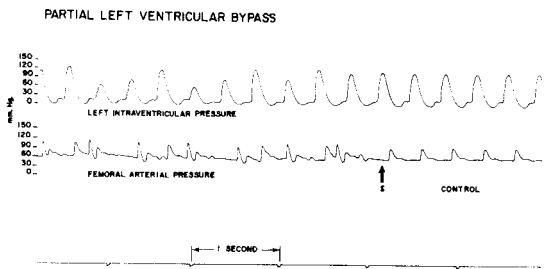


Figure 4. Left intraventricular pressure during left ventricular bypass without electrocardiographic triggering. See explanation in the text.

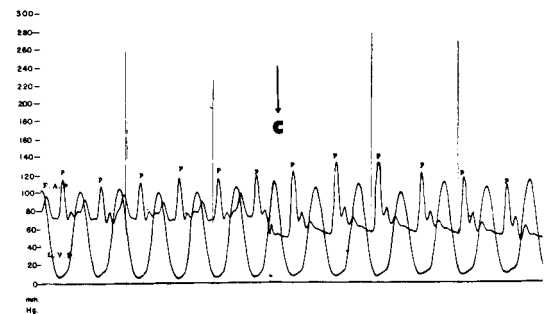


Figure 5. Femoral arterial pressure and left intraventricular pressure during diastolic pumping with an intrathoracic pump. P = femoral pressure wave produced by pump during diastole. After C, the thoracic aorta proximal to the pump's outlet connection was clamped. In this condition only the femoral pressure originating from the pump was recorded.

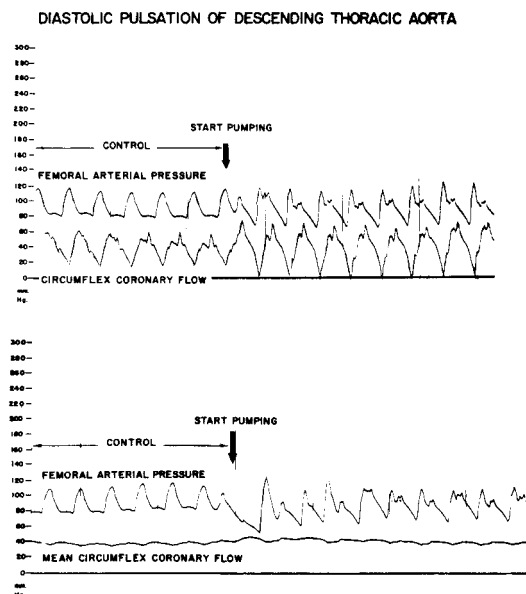


Figure 8. Circumflex coronary artery flow measurement with electromagnetic flowmeter (3 mm. probe, gain 1.0) during diastolic compression of descending thoracic aorta. Circumflex coronary artery flow was 76.7 ml./min. before pumping and increased to 85.04 ml./min. during pumping.